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REVIEW ARTICLE

A review of methods for monitoring streamflow for sustainable water resource management

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Abstract Monitoring of streamflow may help to determine the optimum levels of its use for sustainable water management in the face of climate change. We reviewed available methods for monitoring streamflow on the basis of six criteria viz. their applicability across different terrains and size of the streams, operational ease, time effectiveness, accuracy, environmental impact that they may cause and cost involve in it. On the basis of the strengths and weaknesses of each of the methods reviewed, we conclude that the timed volume method is apt for hilly terrain having smaller streams due to its operational ease and accuracy of results. Although comparatively expensive, the weir and flume methods are suitable for long term studies of small hill streams, since once the structure is put in place, it yields accurate results. In flat terrain, the float method is best suited for smaller streams for its operational ease and cost effectiveness, whereas, for larger streams, the particle image velocimetry may be used for its accuracy. Our review suggests that the selection of a method for monitoring streamflow may be based on volume of the stream, accuracy of the method, accessibility of the terrain and financial and physical resources available.

Keywords Ecosystem services · Water resource management · Streamflow monitoring · Fresh water · Climate change

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Introduction

The availability and distribution of freshwater is of grave concern, since only 2.5% of it covers the earth's surface, only a fraction of which is accessible via lakes, reservoirs and river systems (Berner and Berner 2012). Freshwater plays multiple roles as supporting, regulating, provisioning and recreational services (Millennium Ecosystem Assessment 2005; Smith et al. 2006; Greiber 2009; Gleick 2014) (Table 1). Considering the importance of freshwater systems to human well-being, natural processes and properties that maintain freshwater ecosystems need to be monitored at both local and global scales (Karr 1991; United Nations 2011). Alteration in the natural systems due to human or natural activities may affect the hydrological regime, which in turn affects the ecosystem level processes that affect the availability of water resources (Vogel et al. 2015; Bonacci et al. 2015). Change in water regimes can occur due to decreased or increased availability of water through precipitation, runoffs, groundwater recharge and discharge. This may also be affected by seasonality, frequency, duration, magnitude and timing of flow events (Beavis et al. 2010).

The availability of water affects the natural process such as the ability of soil to retain and purify water, frequency and rate of recharge, which eventually changes the local or regional vegetation type. The alteration in the hydrological regime is considered as a major factor contributing to the loss of biological diversity and ecological functioning of aquatic ecosystems (Bunn and Arthington 2002; Dale et al. 2016). There is substantial uncertainty in trends of hydrological variables due to large regional differences and limitations of the spatio-temporal monitoring networks (Bates et al. 2008; Baltas 2009).

Table 1 Water-related ecosystem services (modified from: Smith et al. 2006; Greiber 2009)

Type of service	Description	Example
Provisioning services	Direct supply of food and non-food products depending on water flow	1. Access to freshwater
		2. Agricultural production
		3. Livestock production
		4. Fisheries and marine products
		5. Production of hydro-electric power
		6. Water transport trade
Regulating services	Related to regulating flows and reducing hazards	1. Buffering of runoff soil water infiltration ground water, maintenance of base flows
		2. Regulation of soil nutrient
		3. Prevention of disaster, i.e. landslide, flood, land erosion drought (risk management)
		4. Regulation of surface and ground water
		5. Regulating micro-climate
Supporting services	Provided support to habitats and ecosystem functioning	1. Stabilizing wildlife habitats
		2. Upholding flow required to maintain downstream habitat and uses
Cultural services	Related to reservation and human inspiration	1. Aquatic recreation
		2. Landscape esthetic
		3. Cultural heritage and identity
		4. Religious value (sacred pond, rivers)

Streamflow, in developed nations, is being monitored since late nineteenth century for better management and allocation of water resources (Barrows 1998), while in developing countries, streamflow monitoring is largely understudied. Monitoring streamflow can potentially be used to study the impact of climate change on water resources, help understand trends of natural hazards, e.g, flash floods, cloudbursts, landslides, rockslides and avalanches, and can be applied for the assessment of freshwater services or water retained by different landscapes (Table 1) (Naithani et al. 2001; Mazari and Sah 2004; Haritashya et al. 2006; Huntington 2006; Mata and Budhooram 2007; Chen et al. 2014). It can provide baseline information about the status and trend in water resource degradation. Since effective management practices in smaller and larger areas can restore degraded ecosystems, measuring flow is significant as it provides information for effective policy and management interventions for efficient economic and ecological water allocation, e.g., extraction and allocation of resources for agriculture and domestic uses and relief management, activities to meet the immediate needs during natural hazards such as landslide, land erosion, flood and drought. It can also be used as a tool to understand the contribution of water to economic development and human well-being (Acreman 2001), enabling societies to allocate water to its highest social value (Moran and Dann 2007) (Fig. 1). Efficient economic allocation of water ensures the availability of water resources for direct human use such as drinking, domestic use, agricultural use, etc., while, efficient ecological water allocation ensures availability of resources for indirect human use in terms of provision of several ecosystem services that support human society (Acreman 2001; Reddy et al. 2015). However, most of the studies on stream monitoring focus on run-off and soil erosion estimation. Some key previous studies have been summarized in Table S1.

The main objective of this review was to compare the various techniques of streamflow monitoring and identify the most suitable methods for monitoring streams of varied sizes across different terrains in developing countries. These methods can then be used for (a) quantification of available water resources, and (b) identification and mapping for the payment of freshwater services provided by different landscapes, especially the water retained by the different forest types. This paper brings together the current technical knowledge for successful implementation of water resources management strategies in developing countries. In the developing countries scenario, most of the managers have access to cheap human resource (mainly untrained and unskilled labor) but lack technical infrastructure and accessibility to monitoring sites due to harsh weather conditions and low connectivity.

Methods

We first gathered literature on streamflow and its measurement through online web based search engines, using keywords such as, streamflow, stream discharge, direct

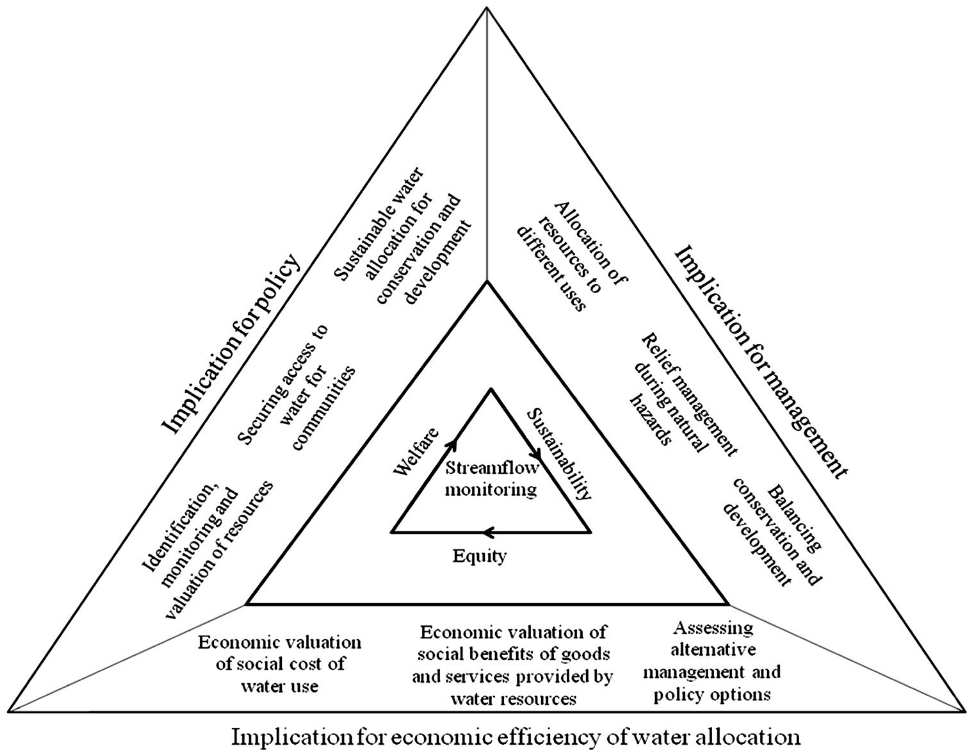

Fig. 1 Implication of stream flow monitoring for policy and financial management

measurement method of stream discharge monitoring, velocity-area method, formed constriction, constricted flow methods, current meters, timed volume method, float method, dilution gauging, trajectory method, weir method, flume method, water resource monitoring and sustainable water identification and management. Web-based resources and online technical databases such as ScienceDirect, JSTOR, Wiley Online Library and Google Scholar were searched and relevant literature was downloaded. The literature thus collected was thoroughly reviewed and six criteria viz. terrain of the stream, accuracy, cost effectiveness, operational ease, time efficiency and impact on environment were identified (Baker 1990; Mittelbach et al. 2012) to compare the methods and a comparison matrix was prepared (Dobriyal et al. 2012; Qureshi et al. 2012) (Table 2). For the present work, terrain of the stream is whether stream is in hills or in flat terrain; accuracy is the degree to which results are free from error; operational ease is the simplicity of data collection in the field and data analysis afterwards; cost effectiveness refers to relative costs incurred in the operation and maintenance of a particular method; time efficiency is the time taken for data collection for one reading and its analysis and to maintain the equipment used; impact on environment is the impact of technique or method on the surrounding environment and wildlife. The criteria were measured against a binary index by assigning one point for advantageous quality and zero if a criterion was not fulfilled by the particular method. Differential weights were subjectively accorded to these above-mentioned criteria in accordance with the importance. The final score was the product of the weights of the criteria and the index value of the method for that particular criterion (Table 3).

Review of methods used for streamflow monitoring

Methods for streamflow monitoring are specific to stream types. Stream channels can be classified on the basis of eight major variables—width, depth, velocity, discharge, slope, roughness of bed and bank materials, sediment load and sediment size (John 1978; Singh 2003). Different methods are available to quantify and monitor the surface-water flow. The methods have been grouped into four categories (based on John 1978; Martin 2006; Herschy 2008; Şengörür et al. 2014): (a) direct measurement methods, (b) velocity-area methods, (c) formed constriction or constricted flow methods, and (d) non-contact measurement methods (Fig. 2). A succinct description of methods has been summarized in Table S2, with a brief account of their suitability to different terrains, advantages and disadvantages. A method can be selected on the basis of the volume of water to be measured, the degree of accuracy desired, whether the installation is permanent or temporary and the financial investment required (Tobias et al. 2001; Parker et al. 2004).

Table 2 Comparison of different methods used for streamflow estimation

Method		Operational ease	Cost effectiveness	Accuracy	Time effectiveness	Ecological significance	References	Remarks
Direct measurement method	Timed volume method	Easy	Inexpensive	High	Efficient	Non-polluting	Najafi et al. (2012) and Shope et al. (2013)	The method can be used only for streams with less flow rate and with a fall
Velocity-area methods	Float method	Easy	Inexpensive	Low	Efficient	Non-polluting	Hilgersom and Luxemburg (2012), Watson et al. (2013) and Kitlasten and Fogg (2015)	The method can be used only for small streams
	Dilution gauging method	Difficult	Inexpensive	Low	Efficient	Affects the stream ecosystem	Moore (2004) and Comina et al. (2014)	Difficult to operate and tracer or dye can damage the environment
	Trajectory method	Difficult	Inexpensive	High	Inefficient	Non-polluting	Boman and Shukla (2009) and Liu et al. (2014)	The method can be applied only to streams where flow can be diverted into a pipe
	Current meters method	Difficult	Expensive	High	Efficient	Non-polluting	Chauhan et al. (2014) and Boldt and Oberg (2015)	Current meter can be used only for short term study
	Acoustic Doppler current profiler method	Difficult	Expensive	High	Efficient	Non-polluting	Herschy (2008) and Flener et al. (2015)	The method can only be used where all the flow can be diverted into a pipe
	Electromagnetic method	Difficult	Expensive	High	Efficient	Non-polluting	Herschy (2008)	Accuracy of the estimates get affected by the size of the stream
Formed constriction methods	Weirs method	Difficult	Expensive	High	Inefficient	Non-polluting	Hudson (2004), Martin (2006) and Bonacci et al. (2015)	Construction of the weir on natural streams may alter the local habitat
	Flume method	Difficult	Expensive	High	Inefficient	Non-polluting	Shieh et al. (1996), Baffaut et al. (2015) and Bonacci et al. (2015)	Construction of the structure may alter the local habitat
Non-contact measurement methods	Remote sensing method	Difficult	Expensive	Low	Efficient	Non-polluting	Ward et al. (2013) and Birk and Ecke (2014)	It covers larger areas in less time but results need ground truthing
	Particle image velocimetry	Difficult	Expensive	High	Efficient	Non-polluting	Hauet et al. (2008) and Adrian and Westerweel (2011)	This method covers larger areas and yield accurate results but estimates need to be validated and cannot be used in hilly terrain

Table 3 Binary index developed for the different methods against identified criteria

Different Criteria (weight)	Timed volume method	Float method	Dilution gauging method	Trajectory method	Current meter	ADCP method	Electromagnetic method	Weir method	Flume method	Remote sensing	Particle image velocimetry
Operational ease (2)	2	2	0	0	0	0	0	0	0	0	0
Cost effectiveness (2)	2	2	2	2	0	0	0	0	0	0	0
Accuracy (2)	2	0	0	2	2	2	2	2	2	2	2
Time effectiveness (2)	2	2	2	0	2	2	2	0	0	2	2
Impact on environment (3)	3	3	0	3	3	3	3	3	3	3	3
Total weight	11	9	4	7	7	7	7	5	5	7	7

One index value was given to a method for presence of the desired quality and zero if that criterion was not fulfilled by the method. Weight has been given to the different criteria in accordance with the importance of it, subjectively. Final scores were the product of weightage of the criteria and index value of the method for that particular criterion

Direct measurement method

Timed volume or volumetric streamflow method

This method is used for streams where the entire flow converges into a single descend (Hauer and Lamberti 2007; Shope et al. 2013). The time required to fill a container of a known volume is recorded and later used to calculate the average flow rate (Lawson 1995). For reliable and accurate results, container must be of a large size and the flow rate measured at least five times, with more than three replicates for the stream width and depth recorded (Ely 1994; Pfeffer and Wagenet 2007). The flow rate is the ratio of average stream cross section area and average time taken to fill the container. This method is accurate, cost and time effective, non-polluting and requires limited resources and technical knowledge (Friederich and Smart 1982; Najafi et al. 2012). However, this method is suitable only for small and narrow streams (Weight and Sonderegger 2001; Shope et al. 2013).

Velocity-area methods

Velocity-area methods are based on the principle of the continuity of fluid flow. These methods are used for instantaneous measurement of streamflow and to establish the stage–discharge relationship (Harmel et al. 2009).

Float method

In the float method, an object of low density is allowed to float for a known distance in the stream, and the time taken by the float is measured and water speed calculated (Hauet et al. 2008; Gordon et al. 2013). The speed of water and the cross-sectional area is used for calculating the water flow in the stream (Peltz and Schwartz 2008). To overcome error, 5–10 floats should be recorded. The floats should ideally be made of materials such as a water-soaked block of wood, or other natural material that has less per unit area mass and can be easily spotted from a distance (Harrelson et al. 1994; Harwell and Asquith 2011). This is a simple, non-polluting method and does not require extensive resources and high skills (Grant and Brian 1997; Hauer and Lamberti 2007). However, the results are often inaccurate because vertical turbulent motion causes the difference between the velocity of different surfaces of streams and float does not represent the actual flow (Hilgersom and Luxemburg 2012). This method is suitable for small and straight streams or canals with low and even flow (Hudson 1993); its applicability for larger streams is questionable. To overcome this, the integrated float method has been developed (Herschy 1978, 1995; Hilgersom and Luxemburg 2012), where a float is released at the bottom of a river or canal. The float is assumed to rise with a constant velocity, so the depth-integrated horizontal velocity can be determined from the float's displacement as it surfaces (Hilgersom and Luxemburg 2012).

Dilution gauging method

Dilution gauging method measures streamflow on the basis of rate of diffusion of a tracer that can be either a chemical or a radio isotope (Comina et al. 2014; Dingman 2015). Chemical tracers, such as common salt (NaCl), can be used by using an electrical conductivity (EC) meter or an ion electrode (Flury and Wai 2003; Otz et al. 2003).

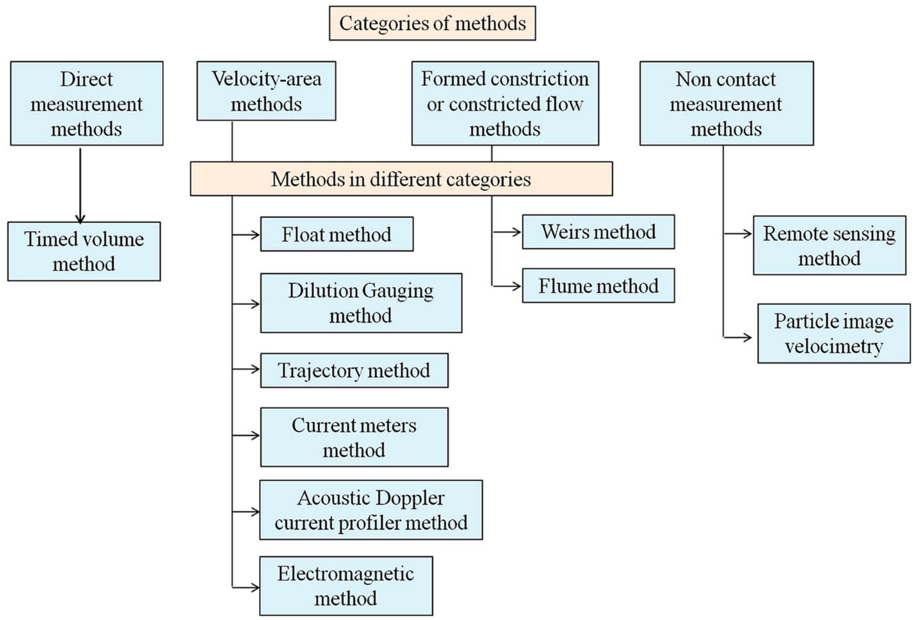

Fig. 2 Existing methods used for stream monitoring (categorized on the basis of principle)

Streamflow is calculated by multiplying average cross section area and velocity of the flow. The method is inexpensive. It is an absolute method because the discharge is computed from volume and time only (Herschy 2008). It is used in turbulent flow conditions where conventional methods are difficult to apply (Gordon et al. 2004). However, the method can report erroneous results due to the loss and incomplete mixing of the tracer arising from the difference in velocity in the upper and lower surfaces of the stream. Special training is needed to apply this method in the field. In certain areas, it is difficult to obtain the permission to inject tracers into streams as it can pollute water (Moore 2004).

Trajectory method

In the trajectory method, all the flow in a stream is diverted into a pipe (Yan 1996; Hudson 2004; Salguero et al. 2008). Flow from a horizontal pipe can be estimated using either the California pipe method developed by van Leer (1924) or the trajectory method developed by Greeve (1928). This flow measurement technique is based on measuring brink depth at the end of the pipe (Berkowitz 2013). The diverted water is discharged with pressure so that the rate of flow can be estimated from measurements of the jet (Rohwer 1943; Boman and Shukla 2009). At least two measurements of the discharging jet are required to calculate the rate of flow of the water (Yan 1996; Liu et al. 2014). The method provides reasonably accurate values of discharge only for certain ranges of size and flow conditions and can be applied to streams where discharge can be diverted through a pipe (Hudson 1993; Boman and Shukla 2009). This method can be adapted for the measurement of discharge in small open channels where flow can be directed to a pipe (Liu et al. 2014). This method needs trained man power and involves complicated calculations (Boman and Shukla 2009).

Current meter method

The current meter method depends on defined channel geometry for the calculation of flow velocities (Briggs et al. 2012; Hamilton and Moore 2012). The current meter measures a point velocity or a velocity field directly. The cross-sectional geometry (channel geometry) is needed to convert the velocity to a discharge. In this method, stream channel cross section is divided into vertical subsections. Area for each subsection is calculated by measuring the average width and depth. The velocity of flow at a point is proportional to the rate of rotation of the rotor during a fixed period of time (Soupir et al. 2009; Chauhan et al. 2014). The discharge is a product of area and measured velocity and is calculated for each subsection. Total discharge is the sum of discharge of subsections. The current meter method is accurate, time effective and suitable for hilly terrains (United States Geological Survey 2007) and so can be used commercially (United States Department of Agriculture 2001). Current meters are expensive and can be used only for a short period.

Acoustic Doppler current profiler method

Acoustic Doppler current profiler method (ADCPs) transmits sound into the water and receives echoes from particles suspended in the stream. The difference in the frequency of the transmitted sound and echoes is used to calculate the velocities of the particles and the water in which they are suspended (Costa et al. 2000, 2006). Mounted on a ship or a boat, ADCPs provide the quasi-continuous vertical profile of horizontal current (Muste et al. 2004; Chauhan et al. 2014). It measures boat speed and direction by tracking the river bottom and compensate for the boat movement in the computation of water velocities (Oberg and Mueller 2007). ADCPs can be classified into two classes on the basis of the techniques used to configure and process the acoustic signal-narrow-band and broadband (Lu and Lueck 1999; Lee et al. 2014). ADCP method measures the stream discharge faster and yields accurate results because ADCPs measure a much larger portion of the water column (Mueller and Wagner 2009). It is non-invasive but costly and needs trained personnel, for if used with inappropriate techniques it may give inaccurate results, and is suitable only for large streams and rivers in flat terrains (Visbeck 2001; Flener et al. 2015). However, the ADCP equipment may be deployed by the use of a tethered boat, or small powered launches or catamarans, where, with the aid of two operators, this method can be used for small rivers (Herschy 2008; Flener et al. 2015). Acoustic velocity meters (AVMs) are not related to the float method. AVMs measure the flow velocity across the channel at one or more fixed levels and an index velocity rating is used to convert this velocity to the cross-sectional average velocity that is used to compute discharge. Some simple, narrow-beam acoustic Doppler velocity meters (ADVMs) measure velocity at a single point in the flow and relate this to the cross-sectional average velocity.

The electromagnetic method

The electromagnetic method measures point velocity of a stream by using an electromagnetic meter. Continuous records of velocity at one point in a cross section and of the stage readings are used to calculate the stream discharge records (Egusa et al. 2013). This method works according to Faraday's law of electromagnetic induction, the motion of water flowing in a stream cuts the vertical component of the earth's magnetic field and an electromotive force (EMF) is induced in the water. This EMF can be sensed by electrodes ('probes') on each side of the stream and is found to be directly proportional to the average velocity of flow in the cross section (Herschy 2008). This method gives accurate results but special training is needed to use the probes (Ryckborst and Christie 1977; Van Gent et al. 2008). Electromagnetic method gives reliable results only for streams where all the flow can be diverted into a pipe (Herschy 2008).

Formed constriction methods

These methods are less influenced by the roughness of the stream and the backwater influence, compared to the velocity-area methods. All formed constriction methods are generally appropriate for small streams.

Weir method

In this method, stream discharge is estimated using a formed check-dam or weir made of plywood, or other wooden boards, and reinforced concrete, in the cross section of a stream (Rickard et al. 2003; Gordon et al. 2013). Weirs are classified into two general categories viz. broad crested and sharp crested (Chaudhry 2008). Broad crested weirs can only be used to calculate instantaneous flows (Gonzalez and Chanson 2007). Sharp crested weirs are constructed in a variety of shapes such as V-notch, rectangular and Cipolletti weirs (Martin 2006). Flow rate can be measured by using a predefined table (British Columbia 2006) or discharge can be estimated using a weir equation, which considers the flow rate, height of water head and width of the crest (Ghodsian 2003; Emiroglu et al. 2011). This method requires skilled workers (Peterson and Cromwell 1993) and considerable drop between the upstream and downstream water surfaces, which is often not available in flat grade ditches. Frequently, it is necessary to construct a pool or stilling area above the weir so the water loses its velocity. Weir installations in earthen ditches can be troublesome and results can be affected by installation and construction (Peterson and Cromwell 1993; George et al. 2011). This method is time consuming, expensive and installation of weirs may alter the habitat for local species (Rickard et al. 2003). Siltation affects the reliability of the results (Hudson 2004). A pre-measured flow rate is needed before constructing a weir (Martin 2006). The weir must be sized to accommodate the range of flow that needs to be measured. In many cases, the natural range of flow is too large to be captured by a single weir. Compound weirs can be used to expand the measured range of flows. Weirs are one of the most accurate methods of measuring water flow (Peterson and Cromwell 1993) and may form an important component of a Water Management Plan (Rickard et al. 2003).

Flume method

A flume is an artificial open channel flow section that restricts the stream area and changes its slope, which increases the velocity and changes the volume of the water flowing through the flume (Ancey et al. 2008). There is no impoundment, but the height of water in the flume is measured with a stilling well (Mutz et al. 2007). The discharge can be calculated by measuring the height of water in the flume. HS, H and HL type flumes are used for measuring intermittent runoff, venturi flume for measuring irrigation water and San dimas Flume for debris laden flows in mountain streams (USFWS 2006). For water flow calculations, tables given by Bos (1976) and Hudson (1993) can be used. Flumes give accurate results when properly manufactured and installed (Hudson 2004) and do not need calibration, but accuracy gets affected by approach velocity of liquid and siltation (Hudson 2004). This method is not suitable for streams with large amount of debris, sediment or solids. Construction and installation are difficult (Shieh et al. 1996; Baffaut et al. 2015). Flumes are not practical except for small streams and are more limited than weirs regarding the range of flows that can be measured. Additionally, flume construction is more difficult than weirs.

The ultrasonic method is particularly applicable to rivers up to about 300 m or more in width, where (a) there is no stable stage–discharge relation, and (b) a measuring structure is unsuitable or not feasible. The method is therefore appropriate under conditions of backwater from dams, tides, or other causes, and where the installation of a measuring structure would either prove too expensive or sufficient afflux, or head, is not available. Ultrasonic river gauging is based on the continuous measurement of stream velocity at chosen depths by recording the difference in time for sound pulses sent obliquely across the river in opposite direction.

Non-contact measurement methods

Most of the above-mentioned methods are feasible in accessible terrains. The non-contact methods can be used for the streams which are not easily accessible. These methods are based on the principle of radar system and may be used to make continuous, near-real-time flow measurements during high and medium flows.

Remote sensing method

Remote sensing method estimates river discharge from space, using ground measurements and satellite data to construct empirical curves that relate water surface area to discharge (Bjerklie et al. 2005; Tan et al. 2014). The sensors used in this method can be (a) passive, in which the sensor receives energy naturally reflected by or emitted from the earth's surface; and (b) active, in which the sensor provides its own illumination and records the amount of incident energy returned from the imaged surface (Xu et al. 2004; Ticehurst et al. 2009). Three general approaches are used to estimate stream discharge: (a) direct measurement of water surface level from radar altimeter waveform data; (b) determination of water surface elevations at their point of contact with the land surface using high-resolution satellite imagery and topographic data; and (c) correlation of satellite-derived water surface areas with ground measurements of stage or discharge (Smith 1997; Papa et al. 2012; Revilla-Romero et al. 2014). Satellite data could provide unprecedented global coverage of critical hydrologic data that is logistically and economically impossible to obtain through ground-based observation networks (Koblinsky et al. 1993; Xu et al. 2004; Batra et al. 2006). Remote sensing is an expensive method and cannot directly estimate the stream discharge (Costa et al. 2000). Larger errors occur in flooded forests because trees are highly reflective in the visible and near-infrared range (Ward et al. 2013). Floating emergent macrophytes also affect the accuracy of the results in tropical systems (Hess et al. 1995; Birk and Ecke 2014). This method can be used for both flat and hilly terrain, but it can estimate the discharge of only larger streams (Immerzeel et al. 2009).

Particle image velocimetry

In the particle image velocimetry (PIV) method, the position of the fluid is represented through the light scattered by liquid or solid particles illuminated by a laser light sheet (Prasad 2000; Tauro et al. 2016). In most of the studies, liquid or solid particles have to be seeded with tracer particles that are small and light enough to move with local flow velocity (Brossard et al. 2009). A flat terrain in which flow need to be calculated illuminated twice by means of two superimposed laser light sheets. The light scattered by the liquid or solid particles is recorded on two separate frames on a CCD camera sensor (Bosbach et al. 2009). The time intervals between the two laser pulses, image magnification produced by camera calibration and projection of the local flow velocity vector onto the plane of the light sheet are used to calculate the small interrogation areas. These small interrogation areas produce one displacement vector. The velocity is the ratio of the particle displacement divided by the time interval between images (Harpold Harpold et al. 2006; Stamhuis 2006). The main advantage of PIV is that it provides high-resolution flow velocity information of a flat surface at one time (Stamhuis 2006). This method requires special training and expensive instruments to take measurements and can be applied only in flat terrains (Adrian and Westerweel 2011). PIV gives accurate results as compared to other methods but does not take direct measurement; hence, validation of results is needed for this method (Hauet et al. 2008).

Conclusions

Monitoring hydrological regimes has gained importance with the increasing concern for impacts of climate change. Stream monitoring forms a critical basis for water resource management. The volume and functions of the streams are controlled by hydrologic processes that can be defined by the geology, topography and climate of the area, along with impact of human activities. Understanding the streamflow and the hydrological processes determining the streamflow is critical for the efficient and optimum allocation of water resources, so as to realize their maximum social and economic value. Information generated through regular monitoring of natural streams/rivers encourages sustainable use of water resources and also facilitates development and implementation of economic tools such as payments for ecosystem services (Fig. 1). A river/stream can be monitored using a method that is appropriate for the objective of the study, resources and expertise availability, stream size and terrain. On the basis of review of literature and qualitative index developed (Table 3), we concluded that, for monitoring small mountain streams, timed volume method is apt and provides a high degree of accuracy. For mountain streams with large quantity of water, weir and flume methods are more efficient and can be used for a long term study. For small streams in flat terrain, float method can be used, whereas, for larger streams, dilution gauging is a better method if tracer is properly added to all the surfaces of the stream and if tracer does not alter water quality (Table S2). The current meter and PIV can be used for more accurate results, although this requires specialized training (Table 2). The present study suggests that the selection of a method for monitoring streamflow may be based on volume of stream, accuracy of the results, accessibility of the terrain and financial and physical resources available.

The policies related to freshwater conservation are likely to become obsolete or no longer responsive to new and changing environmental and political conditions (Woodward et al. 2010; Slate 2014). It has been observed that climate change is consistently associated with changes in a number of components of the water systems (Barnett et al. 2005; Beniston 2012). Governments and water resource managers can use stream monitoring, via prioritized methods, for gathering information needed to plan efficient allocation of freshwater resources and develop possible adaptation strategies/policies to address changing climate conditions.

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